Applications of Intensity-Epicentral Distance Relations to Earthquakes Affecting Indiana

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Abstract

Southern Indiana was ranked as having a seismicity only one order less than the highly seismic western region of the United States (1, 10). Indiana has been severely affected by earthquakes located in neighboring states. Sixteen felt shocks had their epicenters in Indiana. The maximum intensity of the strongest shock was VI$^+$.

A relationship between intensity and distance was established by isoseismal maps for several azimuths. In general, the fall of intensity with distance is given by the relationship:

$$I_o - I = N \log_{10} \frac{(\sqrt{X^2 + H^2})}{H} + A \cdot F$$

where I_o is the maximum intensity, I is the intensity at any epicentral distance, X. H is the depth of focus and N is an empirical term, the value of which depends upon the medium between the focus and the observation point. The last term, A•F, expresses the dispersive nature of intensity loss. A is a numerical constant and F is the frequency of a wave. Having the value of N for various azimuths, and given H, A, F and I_o, I may be computed for any epicentral distance. This technique can be used to determine the effect of predicted earthquakes in a region and to construct probability maps based on past earthquakes.

Seismicity of Indiana and Surrounding States

Sixteen felt earthquakes have occurred in Indiana, ranging in intensity from II to VI$^+$. These earthquakes and their intensities are shown in Figure 1. A list of these earthquakes along with other details is given in Appendix 1. Most of these felt earthquakes affecting Indiana are concentrated in the southwest portion. The greatest intensity, VI$^+$, occurred in Dubois County near Portersville in 1899. An isolated shock of intensity V was located in Porter County near Porter in 1938 (11).

States bordering Indiana are also seismically active. In fact, more damage has occurred in Indiana due to earthquakes located in the neighboring states than due to earthquakes which occurred within the state. The earthquakes which had maximum intensity in Indiana and its neighboring states are listed below. Their locations are shown in Figure 2:

State	Intensity	Year	Location
Illinois	VII	1909	Robinson
Indiana	VI$^+$	1899	Near Portersville
Kentucky	VI$^+$	1916	Near Hickman
Michigan	VII	1877	Near Dearborn
Missouri	X$^+$	1812	New Madrid
Ohio	VII	1937	Anna
Wisconsin	V	1947	Milwaukee

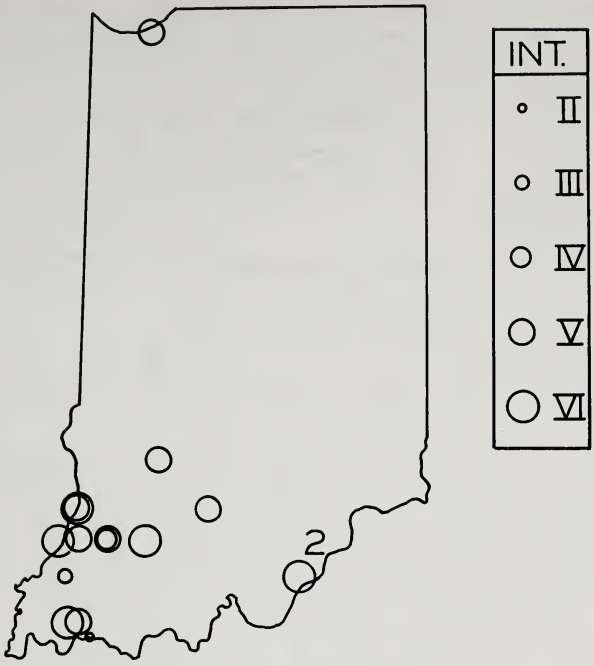

FIGURE 1. *Map locating the epicenters of felt earthquakes—Legend shows intensity symbols. (See also the list of earthquakes given in Appendix 1).*

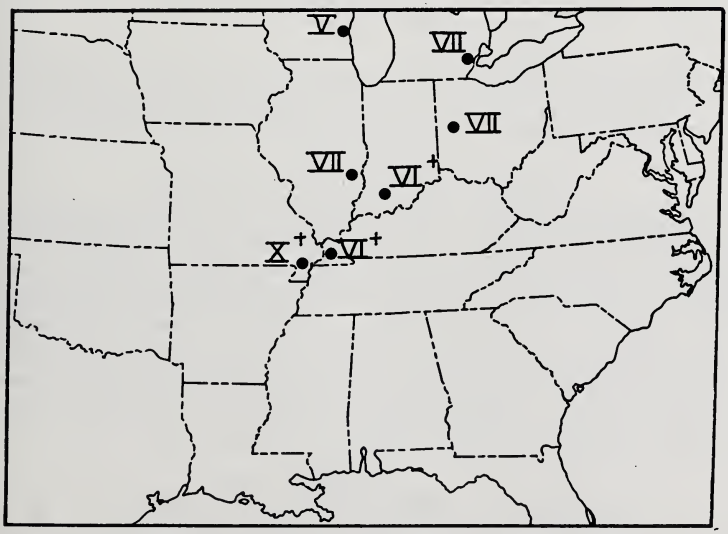

FIGURE 2. *Map of southeastern United States showing maximum intensity past earthquakes in Indiana and neighboring states.*

Figure 3 is a seismic risk map of the United States (1). It was based on the distribution of damaging earthquakes and their intensities. Consideration was also given to geologic structures. Southern Indiana has been put in Zone 2 which is only one order less in seismic risk than the west coast of the United States which has the highest seismic rating. According to this map we can expect to have an earthquake of intensity VII in southern Indiana which can cause moderate damage to existing structures.

FIGURE 3. *Seismic risk map of the United States; after Algermissen (1).*

Intensity-epicentral Distance Relations

The field investigation of an earthquake results in the preparation of an isoseismal map. Such a map represents areas of equal intensity based on the Modified Mercalli Scale (16) where the earthquake had its effects. As an example Figure 4 is an isoseismal map of an earthquake which occurred in Hamilton County, Illinois, in 1968 (3). From such a carefully prepared isoseismal map, one can obtain very important information regarding the nature of the earthquake and the surrounding geological formation. The decrease of intensity with distance from the epicenter is governed by the following relation (5):

$$I_o - I = N \log_{10} \frac{(\sqrt{X^2 + H^2})}{H} + A \cdot F \qquad [1]$$

I_o is the intensity at the epicenter, I is the intensity at any epicentral distance X, H is the depth of focus and N is a constant indicative of

the absorptive capacity of the medium between the focus and the observation point. The value of N generally varies between two and six. A is a second absorption term and F is the frequency of a wave. The value of A ranges from 3 x 10^{-4} to 6 x 10^{-3}. The A•F term is effective only at very short epicentral distances and is usually ignored in macroseismic studies.

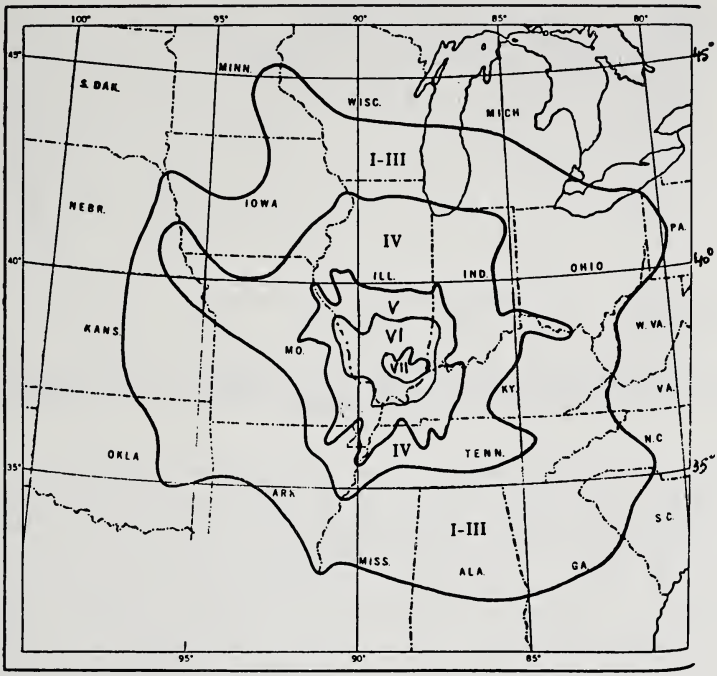

FIGURE 4. *Map showing isoseismal areas of Illinois earthquake of November 9, 1968; after Gordon* et al. *(3).*

Using Equation 1, a family of graphs showing drop in intensity with distance was drawn for various values of N and H. One of these (for N = 3.0) is shown in Figure 5A. The slopes of the lines are constant after a certain distance. In fact, it is the N value in Equation 1. This can be shown as follows:

When X is much greater than H, Equation 1 reduces to the form:

$$I_o - I = N \log_{10} \frac{X}{H}$$

OR

$$= N \log_{10} X - N \log_{10} H \qquad [2]$$

If $I_o - I$ is made equivalent to Y, and $\log_{10} X$ equivalent to X (Fig. 5A) then Equation 2 has the form of a linear equation, Y = NX + constant, where N is the slope. The N value indicates the rate of

decrease in intensity with distance for a particular value of depth of focus H. Higher N values yield higher slopes and a rapid decrease of intensity with distance as shown by a comparison of the steeper slopes for N=5 (Fig. 5B) with the slopes for N=3 (Fig. 5A). Thus N is indicative of the absorption capacity of the medium between the focus and the point of observation.

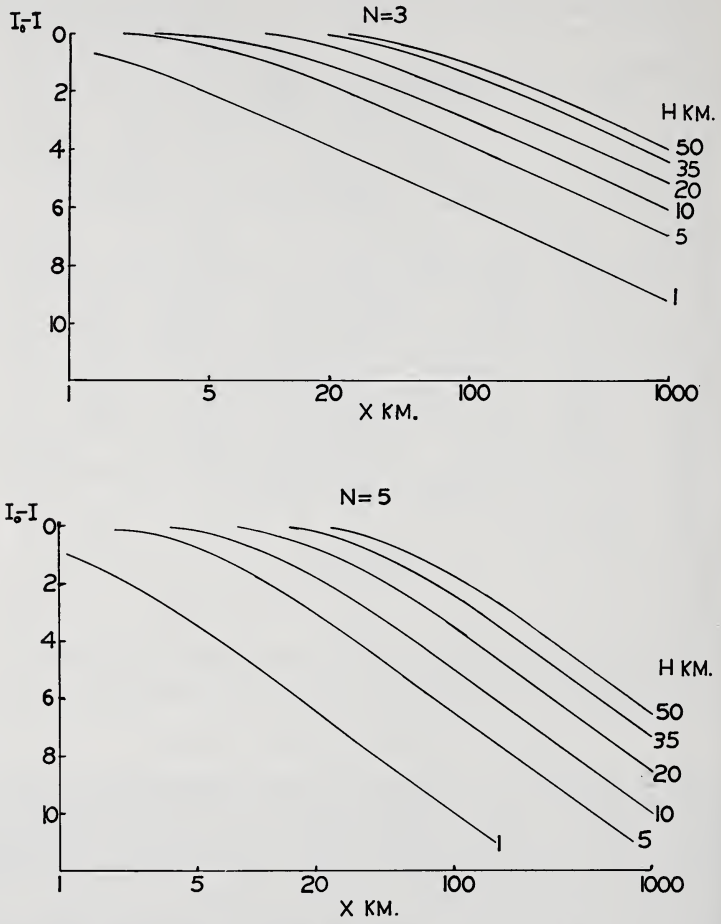

FIGURE 5. *Theoretically evaluated decrease of intensity with distance curves for various values of depth of focus H. A. Above—For N=3.0; B. Below—For N=5.0.*

Application of Intensity-epicentral Distance Relations

Such plots may be used to determine the value of N and depth of focus H from an isoseismal map. As an example, the slope of the decrease of intensity with distance curve (Fig. 6) computed from the isoseismal map (Figure 4) of the 1968, southern Illinois earthquake, gives an N value of 3.1. Comparing this curve with the computed

intensity *versus* distance curve for N=3.0, the depth of focus is shown to be 31 km, which agrees fairly well with the computed value of 25 ± 5 km from phases read from seismograms.

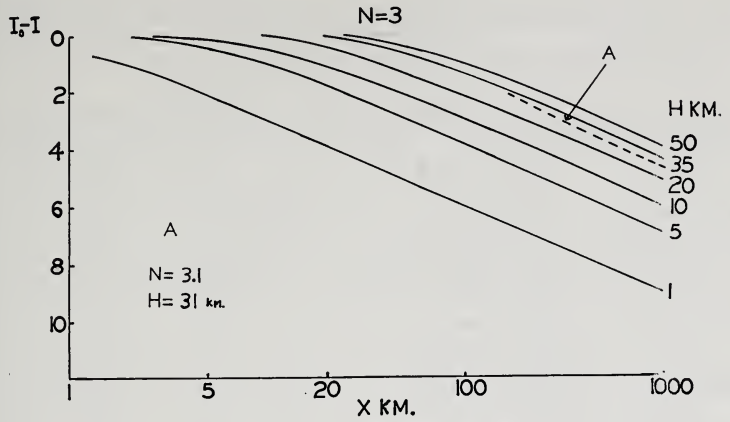

FIGURE 6. *Decrease of intensity with distance curve for Hamilton County, Illinois, earthquake of November 9, 1968; (Dashed Line A). By interpolation we find N=3.1 and depth of focus H=31 km.*

N is azimuth dependent because it is indicative of the absorption capacity of the medium between focus and observation point. Data are available in the form of good isoseismal maps for 22 earthquakes in the eastern and central United States for which the value of N has been determined along selected azimuths. The mean value of N and the standard deviation σ, of 2 to 4 determinations for these earthquakes along with other details are given in Table 1. Most of these data are from earthquakes to the southeast, south and southwest of Indiana. Isoseismals for earthquakes located in other regions are being currently constructed from a list of felt earthquakes from all available literature for the eastern and central United States. From a description of each earthquake, a location and intensity have been assigned to it. A list of 715 earthquakes with intensities ranging from II to X+ has been collected for the period 1699-1970.

Future Work

The intensity at any locality may be calculated for any earthquake on the above list from Equation 1 and also the N value for that locality. This technique will be used to make a list of intensities for specific locations. From such a list, ordered by intensity the cumulative probability P_i and return period T_i will be obtained by use of Gumble's (4) statistical method. P_i and T_i is given by the relation

$$P_i = \frac{n_i}{n + 1} \text{ and } T_i = \frac{1}{1 - P_i}$$

where n_i is the cumulative number of shocks and n is the total number of shocks. Using such a technique, we plan to determine the return period of various intensities for the Indiana area.

TABLE 1. *The 22 earthquakes of eastern and central United States for which the value of N has been determined.*

Date	Location	Maximum Intensity	N	σ
Dec. 16, 1811	New Madrid, MO	X^{-}	5.2	0.5
Nov. 2, 1928	Madison Co., NC	VI	6.4	2.2
Aug. 29, 1930	Blandville, KY	IV	2.7	1.3
April 11, 1934	Arthur City, TX	V	3.5	0.5
Jan. 1, 1935	Near Hayesville, NC	V	2.9	0.1
April 9, 1952	Near Oklahoma City, OK	VII	4.5	1.3
Jan. 25, 1955	Lepanto, AR	VI	2.5	0.5
April 9, 1955	Near Sparta, IL	VI	3.5	0.6
Jan. 6, 1956	Near Coldwater, KS	VI	6.1	0.7
Nov. 25, 1956	Wayne Co., MO	VI	2.0	0.2
May 13, 1957	Mitchell Co., NC	VI	5.7	2.9
Nov. 24, 1957	NC-TN border	VI	9.6	5.3
Aug. 3, 1959	Near Goose Creek, SC	VI	3.0	0.6
Oct. 26, 1959	McBee, SC	VI	4.3	2.4
Feb. 2, 1962	Near New Madrid, MO	VI	2.7	0.9
March 3, 1963	Stoddard Co., MO	VI^{-}	5.1	0.6
Oct. 20, 1965	Washington Co., MO	VI^{+}	2.3	0.4
June 4, 1967	Near Greenville, MS	VI	5.0	0.9
Nov. 9, 1968	Hamilton Co., IL	VII^{-}	3.1	0.3
May 2, 1969	Hughes Co., OK	V^{+}	3.4	0.1
Nov. 19, 1969	Mercer Co., WV	VI^{-}	3.7	0.8
Nov. 16, 1970	Blytheville, AR	VI^{-}	6.1	2.4

Conclusions

1) Southern Indiana is in a high seismic risk area. The frequency of occurrence of earthquakes in Indiana is low but in the past the state has been severely affected by earthquakes located in the neighboring states.

2) Depth of focus H and the N value in the decrease of intensity with distance relationship, $I_o - I = N \log_{10} \frac{(\sqrt{X^2 + H^2})}{H} + A \cdot F$ can be evaluated from isoseismal maps. The value of N is related to absorption capacity of the medium between the focus of the earthquake and the observation point.

3) From the N value, an evaluation of intensity value I can be made.

4) Statistical analyses may be used to find the return period and probability of occurrence of an earthquake of any intensity, from the N value and past earthquakes of the region.

Acknowledgement

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APPENDIX 1

List of felt earthquakes having epicenter in Indiana

Sr. No.	Date	Epicentral Region			Intensity	Source of Information
		Location	Lat.° N	Long.° W		
1.	6 Aug. 1827	New Albany	38.3	85.8	VI	(7)
2.	7 Aug. 1827	New Albany	38.3	85.8	VI	(7)
3.	25 Sept. 1876	Near Evansville	38.5	87.6	VI	(2)
4.	6 Feb. 1887	Vincennes	38.7	87.5	VI	(8)
5.	26 July 1891	Evansville	38.0	87.6	VI	(6)
6.	29 Apr. 1899	Near Portersville	38.5	87.0	VI+	(8)
7.	11 May 1906	Petersburg	38.5	87.3	V	(6)
8.	22 Sept. 1909	Near Mitchell	38.7	86.5	V	(2)
9.	27 Sept. 1909	Vincennes	38.7	87.5	V	(9)
10.	25 May 1919	Near Decker	38.5	87.5	V	(9)
11.	26 Apr. 1925	Near Smythe	38.0	87.5	V	(9)
12.	14 Feb. 1929	Near Princeton	38.3	87.6	III	(12)
13.	5 Jan. 1931	Elliston	39.0	86.9	V	(13)
14.	12 Feb. 1938	Near Porter	41.6	87.0	V	(11)
15.	28 Dec. 1940	Near Newburgh	37.9	87.4	II	(14)
16.	9 Aug. 1954	Petersburg	38.5	87.3	IV+	(15)